

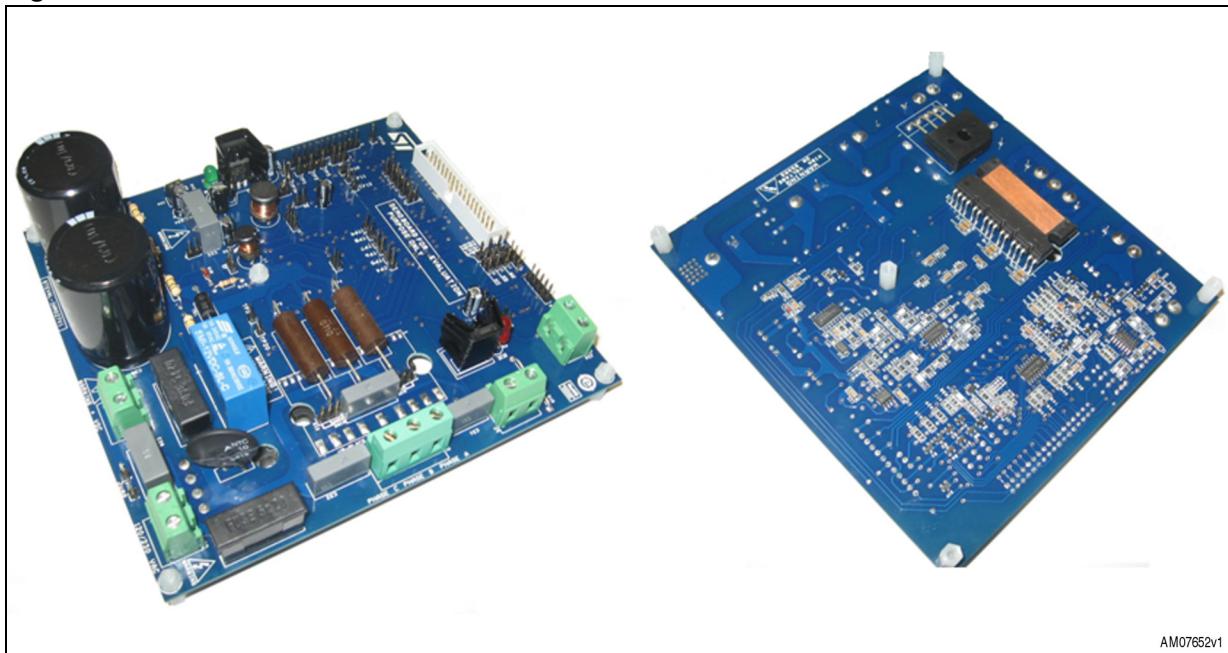
## 3-phase motor control demonstration board featuring IGBT intelligent power module STGIPS10K60A

### Introduction

This document describes the 1 kW 3-phase motor control demonstration board, featuring the STGIPS10K60A: 600 V - 10 A IGBT Intelligent power module. The demonstration board is a 3-phase inverter for driving an induction motor or PMSM motors up to 1000 W. The main target of this application is to show users the performance of the ST 25L-SDIP (25-lead, small dual inline package), IPM - STGIPS10K60A.

The board has been designed to be compatible with a single-phase supply from 90 VAC to 220 VAC, or for DC voltage from 125 VDC to 350 VDC. The document is associated with the release of the STEVAL-IHM027V1 demonstration board (see *Figure 1*).

**Figure 1.** **STEVAL-IHM027V1 demonstration board**



AM07652v1

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# 1 System introduction

## 1.1 Main characteristics

The main characteristics of the STEVAL-IHM027V1 demonstration board are:

- ST IGBT intelligent power module: STGIPS10K60A
- Minimum input voltage 125 VDC or 90 VAC
- Maximum input voltage 350 VDC or 220 VAC
- Possibility to use external +15 V supply voltage
- Maximum output power for motor up to 1000 W
- Regenerative brake control feature
- Input inrush limitation with bypassing relay
- +15 V auxiliary power supply based on buck converter with VIPer16
- Fully populated board conception with testing points
- Motor control connector for interface with STM3210B-EVAL board and further ST motor control dedicated kits
- Tachometer input
- Hall\encoder inputs
- Possibility to connect BEMF daughter board for sensorless six-step control of BLDC motors
- PCB type and size:
  - Material of PCB: FR-4
  - Double side layout
  - Copper thickness: ~45  $\mu\text{m}$
  - Dimension of demonstration board: 147 mm\*157 mm

## 1.2 Target application

- Domestic appliances
- Medical applications, fitness applications
- High power industry pumps
- Medium power fans for HVAC
- Power tools

## 1.3 Safety and operating instructions

### 1.3.1 General terms

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**Warning:** During assembly, testing, and normal operation, the demonstration board poses several inherent hazards, including bare wires, moving or rotating parts and hot surfaces. There is a danger of serious personal injury if the kit or components are improperly used or incorrectly installed. The kit is not electrically isolated from the AC/DC input. The demonstration board is directly linked to the mains voltage. No insulation is ensured between accessible parts and high voltage. All measuring equipment must be isolated from the mains before powering the board. When using an oscilloscope with the demonstration board, it must be isolated from the AC line. This prevents shock from occurring as a result of touching any SINGLE point in the circuit, but does NOT prevent shock when touching two or more points in the circuit. Do not touch the demonstration board after disconnection from the voltage supply; several parts and power terminals, which contain energized capacitors, must be allowed to discharge.

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All operations involving transportation, installation and use, as well as maintenance, are to be carried out by skilled technical personnel (national accident prevention rules must be observed). For the purpose of these basic safety instructions, "skilled technical personnel" are considered as suitably qualified people who are familiar with the installation, use, and maintenance of power electronic systems.

### 1.3.2 Demonstration board intended use

The STEVAL-IHM027V1 demonstration board is designed for demonstration purposes only and must not be used for any commercial purposes. The technical data, as well as information concerning power supply conditions, must be taken from the relevant documentation and strictly observed.

### 1.3.3 Demonstration board installation

The installation of the demonstration board must be in accordance with the specifications and the targeted application.

- The boards contain electro-statically sensitive components that are prone to damage through improper use. Electrical components must not be mechanically damaged or destroyed
- Avoid any contacts with other electronic components
- During the motor drive converters must be protected against excessive strain. In particular, no components are to be bent or isolating distances altered during the course of transportation or handling

### 1.3.4 Electrical connections

Applicable national accident prevention rules must be followed when working on the main power supply with a motor drive. The electrical installation must be completed in accordance with the appropriate requirements. A system architecture which supplies power to the demonstration board must be equipped with additional control and protective devices in accordance with the applicable safety requirements (e.g. compliance with technical equipment and accident prevention rules).

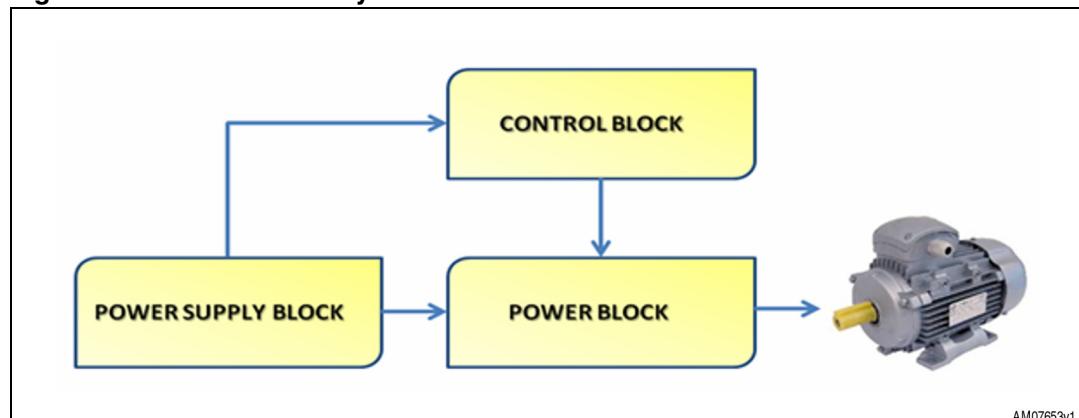
## 2 Board description

### 2.1 System architecture

A generic motor control system can be basically schematized as the combination of three main blocks (see [Figure 2](#)):

- Control block: the main task of this block is to accept user commands and board\motor configuration parameters. The control block provides all digital signals to implement the right motor driving strategy. The STM3210B-EVAL, ST demonstration board, based on an STM32 microcontroller, can be connected to the STEVAL-IHM027V1 thanks to the onboard motor control connector
- Power block: this is based on three-phase inverter topology. The heart of the power block is the STGIPS10K60A integrated intelligent power module which contains all the necessary active components. Please refer to the STGIPS10K60A datasheet (see [References 1](#)) for more information
- Power supply block: able to work from 90 VAC to 220 VAC or from 125 VDC to 350 VDC. Please refer to [Section 3: Hardware setting of the STEVAL-IHM027V1](#), to properly set the jumpers according to the required application

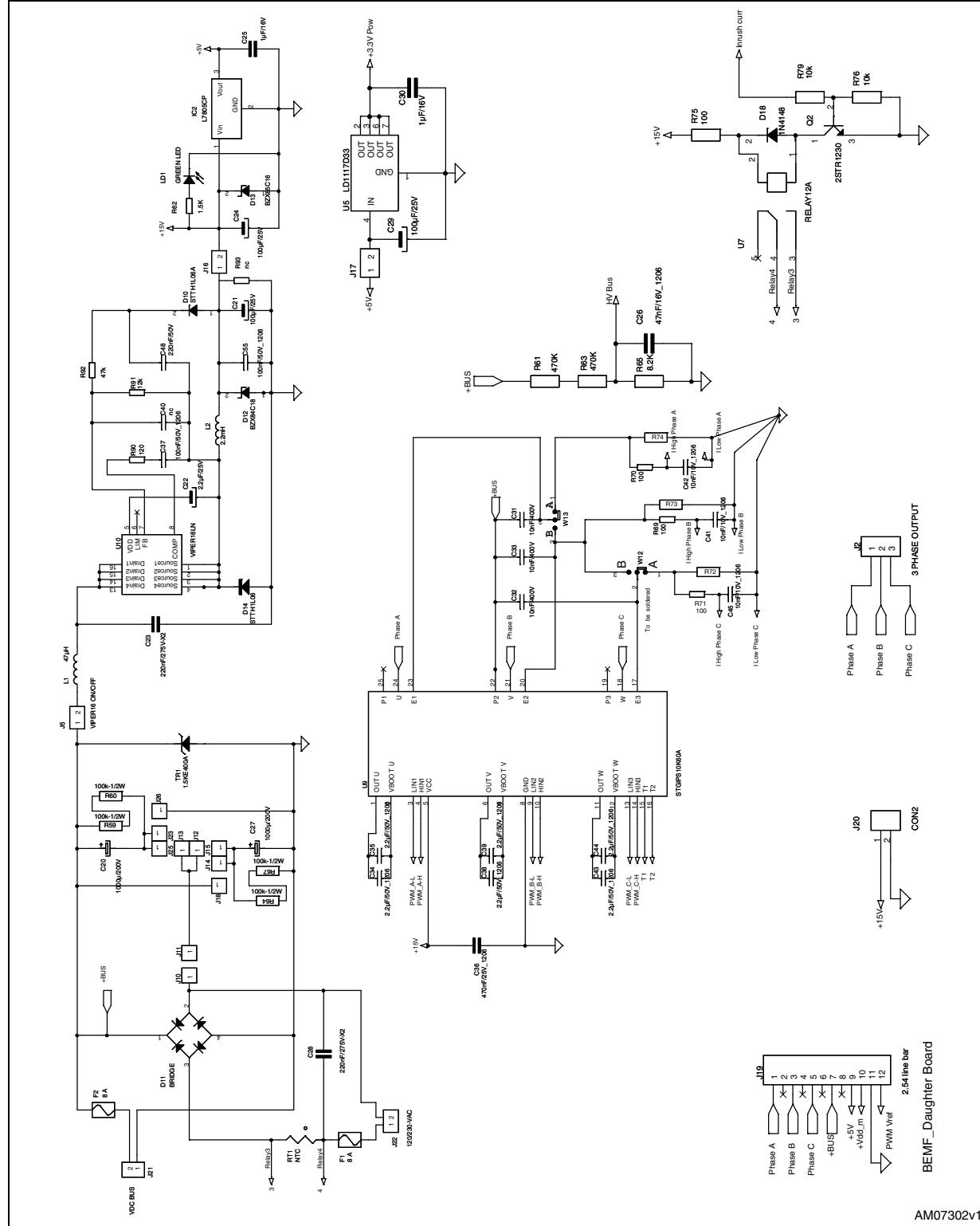
**Figure 2. Motor control system architecture**



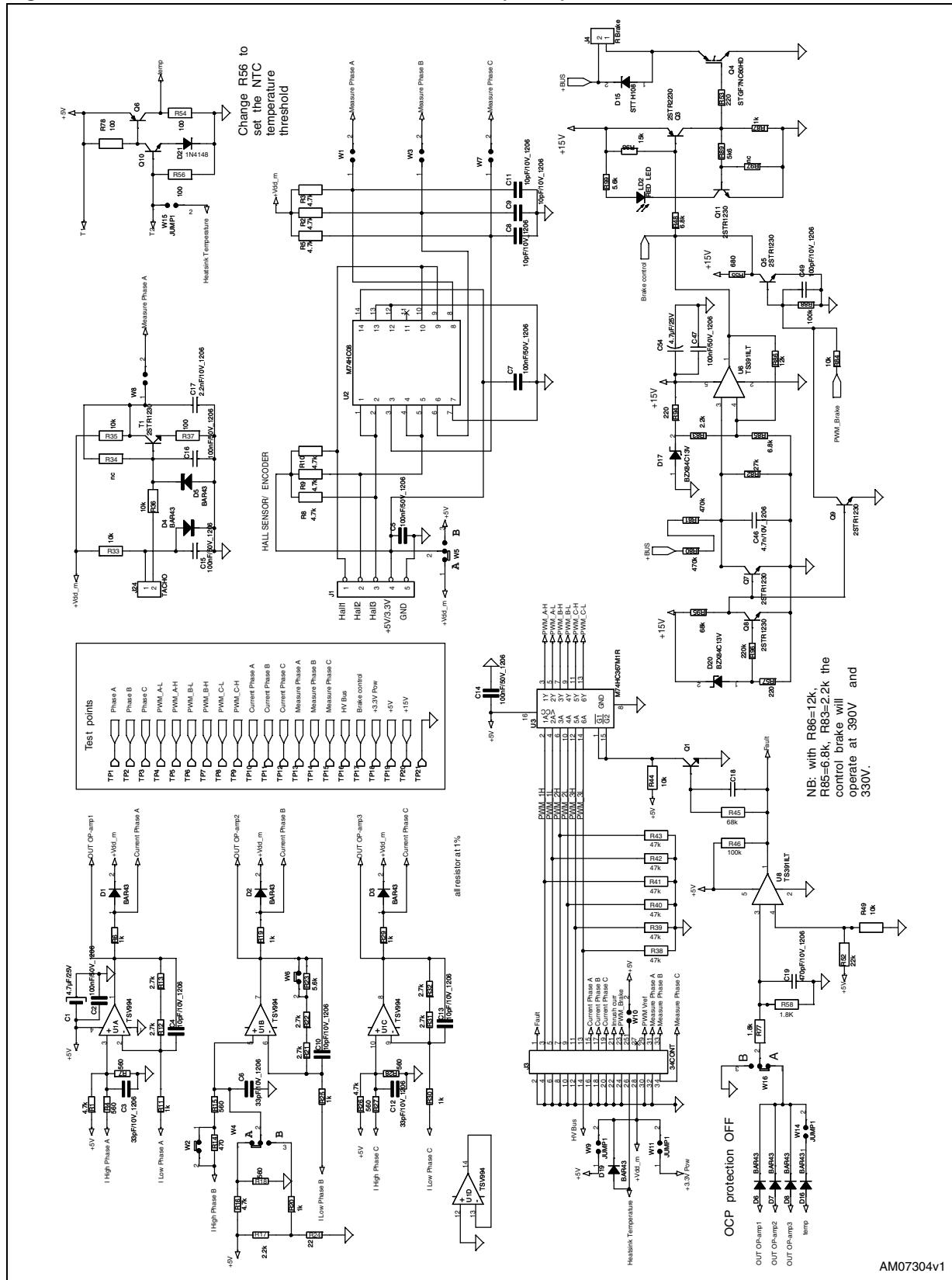
The STEVAL-IHM027V1 includes the power supply and the power block.

## 2.2 Board schematics

**Figure 3. STEVAL-IHM027V1 circuit schematics (1 of 1)**



**Figure 4. STEVAL-IHM027V1 circuit schematics (2 of 2)**



## 2.3 Circuit description

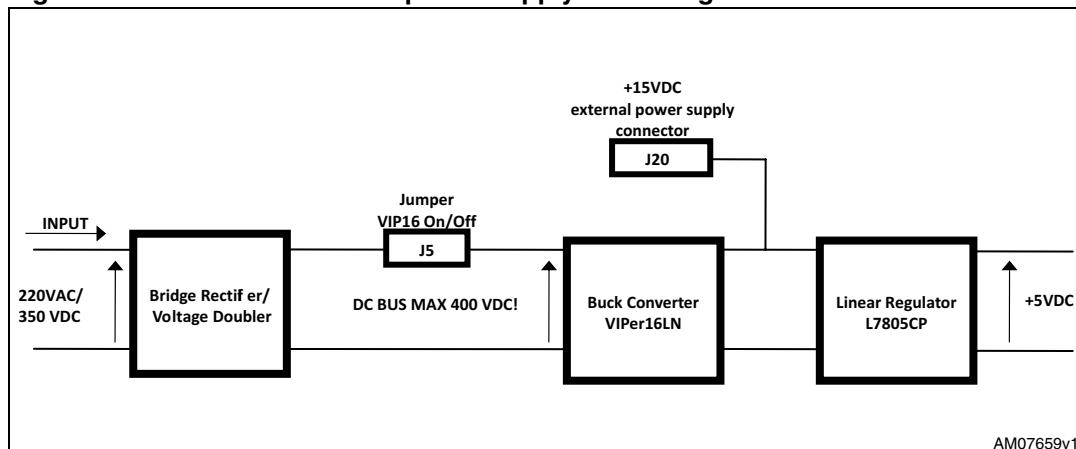
### 2.3.1 Power supply

Power supply of the STEVAL-IHM027V1 is realized as a multifunctional block which allows the inverter to be supplied up to +350 V.

The auxiliary power supply, needed for the active components on the demonstration board, is implemented with a buck converter based on U10 VIPer16, which works with a fixed frequency of 60 kHz. The +15 VDC output voltage is fed into VCC (STGIPS10K60A, PIN 5), as well as into the linear regulator L7805ICP, which provides a +5 VDC for supplying operational amplifiers and further related parts. The presence of +15 VDC on the board is indicated with a green LED (D1).

Please refer to the VIPer16 datasheet (see [References 2](#)) for further information. [Figure 5](#) below describes the power supply block diagram.

**Figure 5. STEVAL-IHM027V1 power supply block diagram**



### 2.3.2 Inrush limitation

The input stage of the demonstration board is provided with an NTC resistor (RT1) to eliminate input inrush current peak during bulk capacitors charging. It is possible to achieve a higher inverter efficiency to bypass this resistor after the startup phase. The driving signal of the bypassing relay is provided directly from the MCU board through the J3 motor control connector (pin 21).

### 2.3.3 Brake function

A hardware brake feature has been implemented on the STEVAL-IHM027V1. An external resistor can be connected to the board thanks to the J4 connector. It represents a dummy load connected directly to the bus, in order to eliminate any overvoltage condition generated by the motor operating as a generator.

Voltage on the bus is sensed through a voltage divider net (resistors R80, R81, and R82), and it is compared to the voltage reference of U6.

The brake dummy load is switched on when the bus voltage reaches 390 VDC and switched off when the voltage decreases to below 330 VDC.

The brake function can be also activated by the microcontroller thanks to the motor control connector (connector J3, pin 23 PWM\_BRAKE signal). The brake threshold levels can be modified by calculating R83, R85, and R86 new values.

### 2.3.4 Overcurrent protection (OCP)

On the STEVAL-IHM027V1 a simple overcurrent HW protection has been implemented. The three TSV994 outputs (pin 1, 7, 8) are the inputs for a discrete OR logic (realized with diodes D6,D7,D8). OR logic output, the biggest op-amp output voltage, is compared to a fixed threshold voltage (set by the R52-R49 voltage divider). When this threshold is passed, transistor Q1 is switched on, setting the enable signals to 0 V (/G1/G2) of M74HC367 and interrupting the PWM signal path, from the MCU to the STGIPS10K60A logic input. When an OCP event occurs, the FAULT signal (connector J3, pin 1 FAULT signal) is also activated to communicate with the MCU. The current protection limit value is also defined by the current sensing amplifying network, described in the next paragraph, because its value must be chosen according to the maximum amplifiable current without distortions. With the chosen value, the STEVAL-IHM027V1 OC protection limit is set to 6 A.

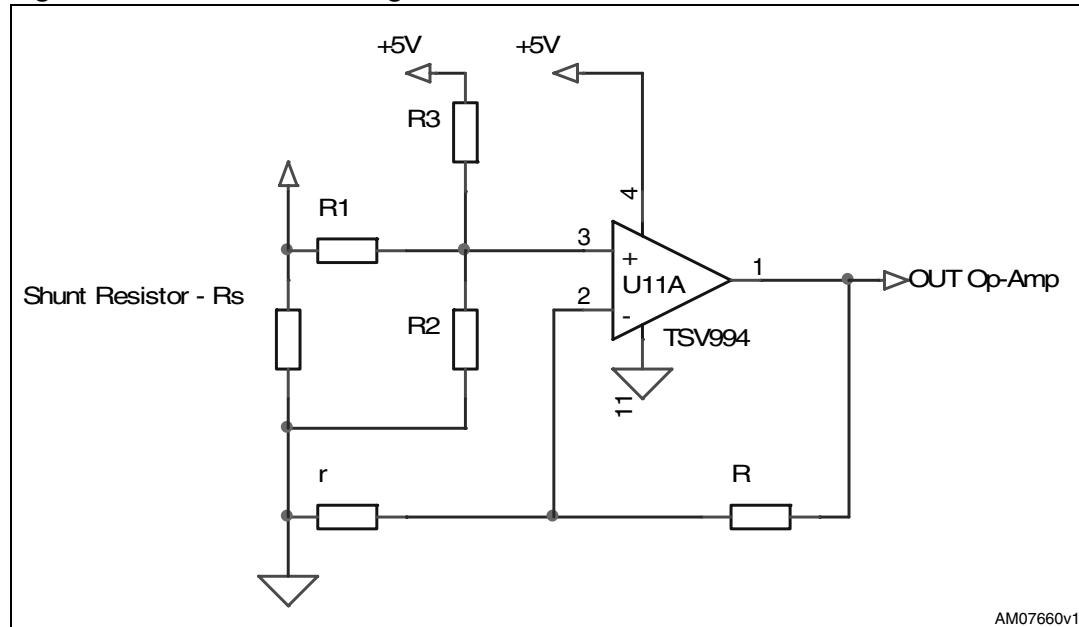
The OCP can be disabled by moving the jumper W16 from position "A" to position "B". It is possible to reach a higher current value but the demonstration board does not protect itself during an overcurrent event. This test must be carried out by skilled technical personnel according to the common accident prevention rules.

### 2.3.5 Current sensing amplifying network

## Three-shunt current reading configuration

Three-shunt current reading configuration details are shown in *Figure 6*. The alternating signal on the shunt resistor, with positive and negative values, must be elaborated to be compatible with the positive input of the microcontroller A/D converter.

**Figure 6. Three-shunt configuration**



Default values for the STEVAL-IHM027V1 are:

- $r = 1 \text{ k}\Omega$  (R11, R25, R30)
- $R = 5.4 \text{ k}\Omega$  (R12-13, R21-22, R31-32)
- $R1 = 560 \Omega$  (R4, R15, R27)
- $R2 = 560 \Omega$  (R7, R18, R28)
- $R3 = 4.7 \text{ k}\Omega$  (R1, R16, R26)

The op amp is used in follower mode and its gain can be set by resistor  $r$  and  $R$ :

#### Equation 1

$$G = \frac{R + r}{r}$$

$V_{\text{OUT}}$  (op amp output voltage) can be calculated as a sum of two components:

- $V_{\text{BIAS}}$ : due to network polarization
- $V_{\text{SIGN}}$ : the signal component

#### Equation 2

$$V_{\text{OUT}} = V_{\text{SIGN}} + V_{\text{BIAS}}$$

$V_{\text{OUT}}$  maximum value is 3.3 V according to the MCU maximum input rating.

#### Equation 3

$$V_{\text{BIAS}} = \frac{5}{\left( \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \right) \cdot R3} \cdot G$$

#### Equation 4

$$V_{\text{SIGN}} = \frac{I \cdot R_s}{\left( \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \right) \cdot R1} \cdot G$$

#### Equation 5

$$G_{\text{TOT}} = \frac{V_{\text{SIGN}}}{R_s \cdot I} = \frac{G}{\left( \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \right) \cdot R1}$$

With the default values:

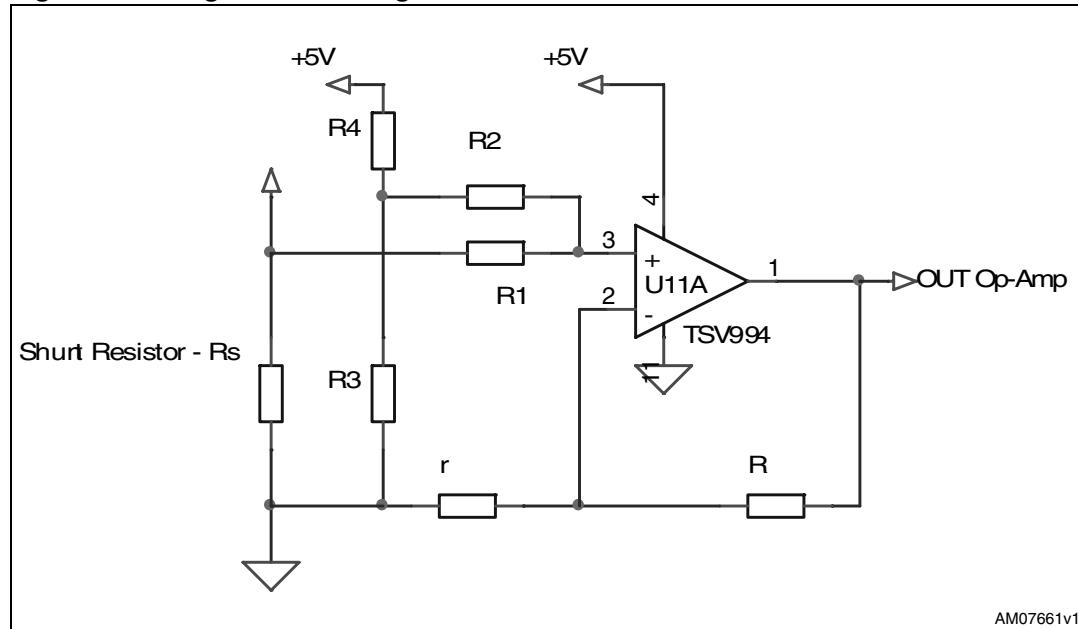
- $G = 6.4$
- $V_{\text{BIAS}} = 1.8 \text{ V}$
- $G_{\text{TOT}} = 3$
- Maximum current amplifiable without distortion is 5 A

It is possible to modify the maximum current value by simply changing the resistor values.

### Six-step (block commutation) current reading configuration

In the case of six-step (also called block commutation) current control, only two motor phases conduct current at the same time. Therefore, it is possible to use only one shunt resistor. Moreover, as the current flows always in the same direction, only a positive value has to be measured. A proper amplifying network needs to be redesigned (see [Figure 7](#)).

**Figure 7. Single-shunt configuration**



See [Table 1](#) to properly set the jumpers for single-shunt current reading:

**Table 1. Jumper settings for a single-shunt or three-shunt configuration**

Jumper	Gain setting	
	Single-shunt	Three-shunt
W2	Not present	Present
W4	B position	A position
W6	Not present	Present
W12	B position	A position
W13	B position	A position

Default values for the STEVAL-IHM027V1 are:

- $r = 1 \text{ k}\Omega$  (R25)
- $R = 5.4 \text{ k}\Omega + 5.6 \text{ k}\Omega$  (R21, R22, R23)
- $R1 = 560 \Omega + 470 \Omega$  (R14, R15)
- $R2 = 1000 \text{ k}\Omega$  (R20)
- $R3 = 22 \Omega$  (R24)
- $R4 = 2.2 \text{ k}\Omega$  (R17)

The op amp is used in follower mode and its gain can be set by resistor  $r$  and  $R$ :

#### Equation 6

$$G = \frac{R+r}{r}$$

$V_{OUT}$  (op amp output voltage) can be calculated as a sum of two components:

- $V_{BIAS}$ : due to network polarization
- $V_{SIGN}$ : the signal component

#### Equation 7

$$V_{OUT} = V_{SIGN} + V_{BIAS}$$

$V_{OUT}$  maximum value is 3.3 V according to the MCU input maximum rating.

#### Equation 8

$$V_{BIAS} = \frac{[R1/(R1+R2)]5}{\left(\frac{1}{R4} + \frac{1}{R3} + \frac{1}{R1+R2}\right) \cdot R4} \cdot G$$

#### Equation 9

$$V_{SIGN} = \frac{((R3//R4) + R2)I \cdot R_s}{(R3//R4) + R2 + R1} \cdot G$$

With the default values:

- $G = 12$
- $V_{BIAS} = 0.3$  V
- Maximum current amplifiable without distortion is 5 A

It is possible to modify the maximum current value by simply changing the resistor values.

### 2.3.6

#### Tachometer and Hall/encoder input

Both the tachometer and Hall/encoder inputs have been implemented on the STEVAL-IHM027V1. In the case of using a Hall or encoder sensor, the W1, W3, and W7 jumpers must be connected and the W8 jumper disconnected. The W5 jumper set in position A allows any connected Hall sensor to be supplied with the same supply voltage of the MCU (+3.3 VDC or +5 VDC depend on the W1 jumper). Setting the W12 jumper to position B supplies the Hall sensor directly with +5 VDC, which is the most common voltage for a Hall sensor. In the case of using a tachometer, the W1, W3, and W7 jumpers must be disconnected and the W8 jumper connected. This type of adjustable feature allows for the testing and evaluating of motors with a wide spectrum of various sensors.

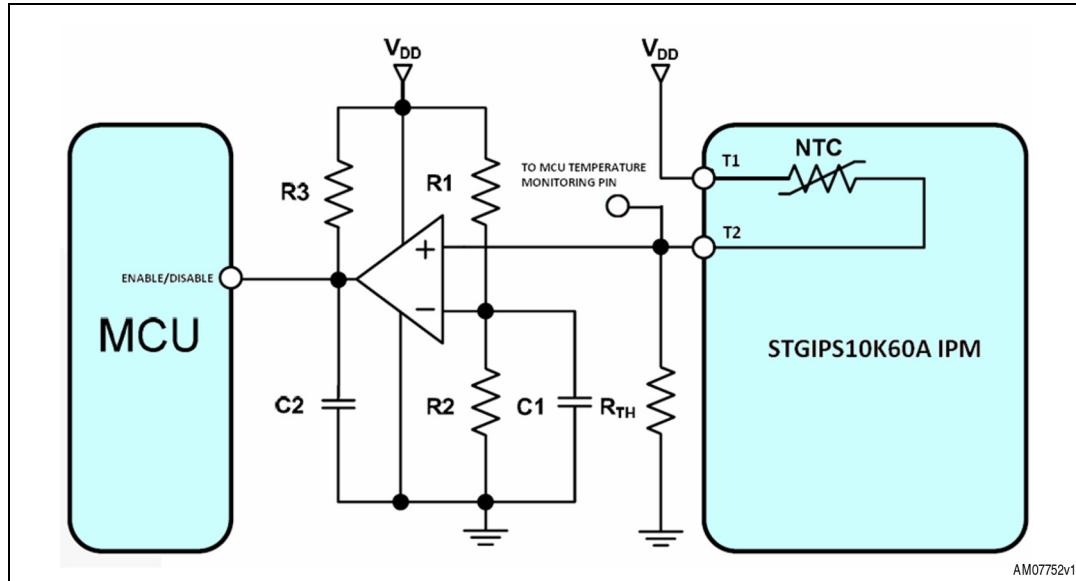
### 2.3.7

#### Temperature feedback and overtemperature protection (OTP)

The STGIPS10K60A integrates an NTC for temperature monitoring purposes. A simple voltage divider is realized with the internal NTC (see [Table 2](#) for NTC details) and resistor R56. The temperature monitoring signal is sent to the MCU through J3 connector (pin 26 HEATSINK TEMPERATURE) and can be read with an AD converter.

The STEVAL-IHM027V1 includes a hardware OT protection that stops the PWM signal path from the MCU to STGIPS10K60A logic input once the maximum allowable temperature is passed. With the chosen value, the OT protection limit is set to 70 °C. Another suggested scheme, generally adopted for temperature monitoring and protection, is shown in [Figure 8](#). The NTC voltage is directly monitored by the MCU and an additional comparator enables/disables the board, according to the temperature thresholds.

**Figure 8.** OT protection circuit



**Table 2.** Internal IPM NTC details (see relevant section on the STGIPS10K60A datasheet)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
R25	Resistance	TC = 25 °C		5		kΩ
R125	Resistance	TC = 125 °C		300		Ω
B	B-constant	TC = 25 °C		3435		K
T	Operating temperature		-40		125	°C
P	Max. rating power (max power on free air)			400		mW

### 3 Hardware setting of the STEVAL-IHM027V1

The STEVAL-IHM027V1 demonstration board can be driven through the J3 motor connector by various control units released by STMicroelectronics. The demonstration board is suitable for field oriented control as well as for tachometer or Hall sensor closed-loop control. The STEVAL-IHM027V1 demonstration board ideally fits with the STMicroelectronics' released STM3210B-EVAL board, based on the STM32 MCU family, as the control unit for FOC driving algorithms.

#### 3.1 Hardware settings with single-shunt configuration

To drive any high PMSM or AC induction motor, the user must ensure that:

- The motor control demonstration board is driven by a control board that provides six output signals required to drive the 3-phase power stage
- The motor is connected to J2 motor output connector
- If using an encoder or Hall sensor, connect it to J1
- If using a tachometer sensor, connect it to J24
- If using the brake control feature, connect a dummy load to J4

*Table 3* shows jumper settings for any motors. Please be sure that the input voltage (mains voltage) of the demonstration board is: from 90 VAC to 220 VAC or from 125 VDC to 350 VDC.

**Table 3. Jumper settings for single-shunt configuration**

Jumper	Settings for single-shunt configuration	
	HV PMSM motor	Generic AC motor with tachometer
W1	Present	Not present
W2	Not present	Not present
W3	Present	Not present
W4	B position for single-shunt	B position for single-shunt
W5	B position to supply Hall sensor\encoder with +5 VCD	B position to supply Hall sensor\encoder with +5 VCD
W6	Not present	Not present
W7	Present	Not present
W8	Not present	Present
W9	User defined	User defined
W10	User defined	User defined
W11	User defined	User defined
W12	B position for single-shunt	B position for single-shunt
W13	B position for single-shunt	B position for single-shunt
W14	User defined	User defined

**Table 3. Jumper settings for single-shunt configuration (continued)**

Jumper	Settings for single-shunt configuration	
	HV PMSM motor	Generic AC motor with tachometer
W15	User defined	User defined
W16	User defined	User defined

### 3.2

## Hardware settings with three-shunt configuration

To drive any high PMSM or AC induction motor, the user must ensure that:

- The motor control demonstration board is driven by a control board that provides six output signals required to drive the 3-phase power stage
- The motor is connected to J2 motor output connector
- If using an encoder or Hall sensor, connect it to J1
- If using a tachometer sensor, connect it to J24
- If using the brake control feature, connect a dummy load to J4

*Table 4* shows jumper settings for any motors. Please be sure that input voltage (mains voltage) of the demonstration board is: from 90 VAC to 220 VAC or from 125 VDC to 350 VDC.

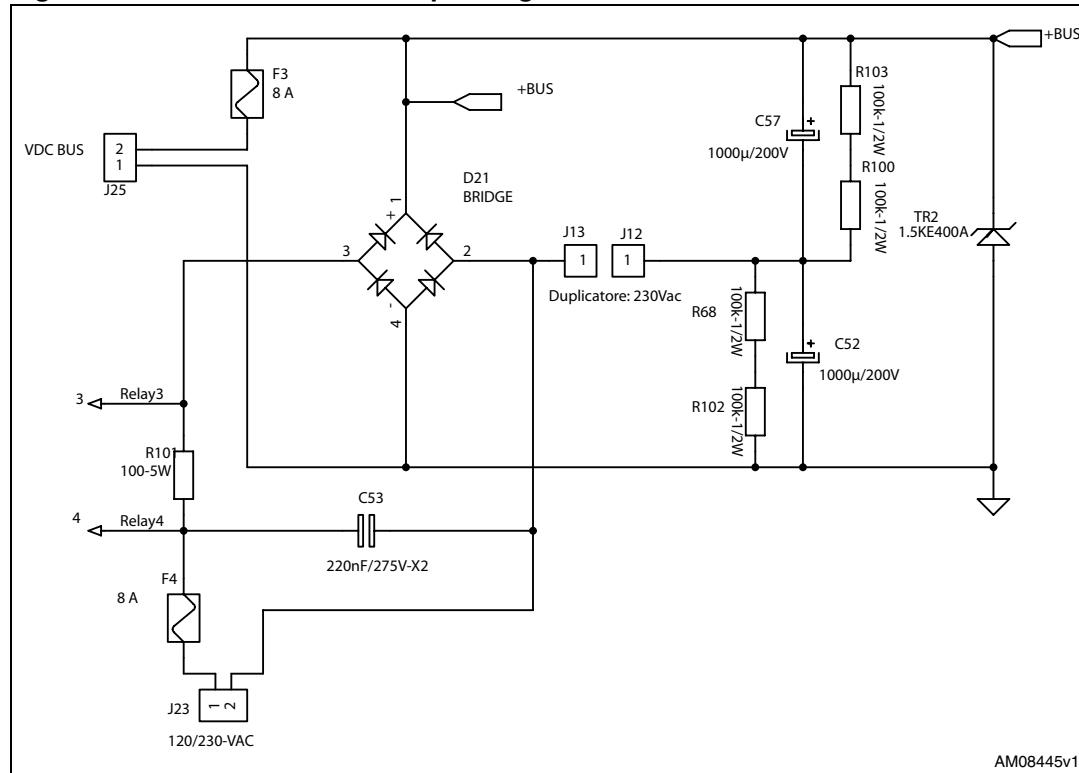
**Table 4. Jumper settings for three-shunt configuration**

Jumper	Settings for three-shunt configuration	
	HV PMSM motor	Generic AC motor with tachometer
W1	Present	Not present
W2	Present	Present
W3	Present	Not present
W4	A position for three-shunt	A position for three-shunt
W5	B position to supply Hall sensor\encoder with +5 VCD	B position to supply Hall sensor\encoder with +5 VCD
W6	Present	Present
W7	Present	Not present
W8	Not present	Present
W9	User defined	User defined
W10	User defined	User defined
W11	User defined	User defined
W12	A position for three-shunt	A position for three-shunt
W13	A position for three-shunt	A position for three-shunt
W14	User defined	User defined
W15	User defined	User defined
W16	User defined	User defined

### 3.3 Hardware settings for input stage

The input stage of the STEVAL-IHM027V1 can be configured according to user needs (see *Figure 9*). Please refer to *Table 5* for detailed information.

**Figure 9. STEVAL-IHM027V1 input stage detail**



**Table 5. Input stage configuration details**

Description	Connections	Note
Voltage doubler	Connect J10 and J11	Maximum allowed DC voltage is 400 VDC
Input capacitors series connections	Connect J25-J13 and J12-J15	Default connections (max DC voltage 400 V)
Input capacitors parallel connections	Connect J23-J26 and J18-J14	Used to increase the input capacitance. Need to change the input capacitors if an increased voltage is required. <sup>(1)</sup>

1. If used with default capacitors never exceed the maximum voltage of 200 V

## 4 Description of jumpers, test pins, and connectors

The following tables give a detailed description of the jumpers, test pins, and the pinout of the connectors used. [Table 6](#) gives a detailed description of the jumpers. [Table 7](#) gives a detailed description of the connectors while [Table 8](#) describes all the test pins placed on the board.

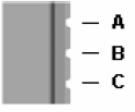
**Table 6. Jumpers description**

Jumper	Selection	Description
W1	Present	Connects tachometer signal to measure phase A
	Not present	Disconnects tachometer signal to measure phase A
W2	Present	Sets the gain of phase B current op. amplifier for three-shunt configuration
	Not present	Sets the gain of phase B current op. amplifier for single-shunt configuration
W3	Present	Connects tachometer signal to measure phase B
	Not present	Disconnects tachometer signal to measure phase B
W4	A position	Sets the gain of phase B current op. amplifier for three-shunt configuration
	B position	Sets the gain of phase B current op. amplifier for single-shunt configuration
W5	A position	Supply hall sensor\encoder with Vdd_m
	B position	Supply hall sensor\encoder with +5 VDC
W6	Present	Sets the gain of phase B current op. amplifier for three-shunt configuration
	Not present	Sets the gain of phase B current op. amplifier for single-shunt configuration
W7	Present	Connects tachometer signal to measure phase C
	Not present	Disconnects tachometer signal to measure phase C
W8	Present	Enable tachometer signal
	Not present	Disable tachometer signal
W9	Present	Set Vdd_m to +5 VDC
	Not present	Set Vdd_m as the same voltage of MCU
W10	Present	Supplies direct driving board through the J3 connector (max. current 50 mA)
	Not present	Separated voltage
W11	Present	Set Vdd_m to +3.3 VDC
	Not present	Set Vdd_m as the same voltage of MCU
W12	A position	Applies shunt resistor to C phase emitter leg
	B position	Setting for single-shunt configuration
W13	A position	Applies shunt resistor to A phase emitter leg
	B position	Setting for single-shunt configuration
W14	Present	“OTP” protection enabled
	Not present	“OTP” protection disabled

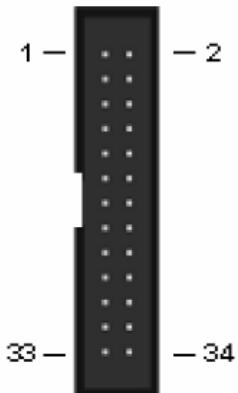
**Table 6. Jumper description (continued)**

Jumper	Selection	Description
W15	Present	GIPS10K60A NTC signal enabled
	Not present	GIPS10K60A NTC signal disabled
W16	A position	“OCP” and “OTP” protection enabled
	B position	“OCP” and “OTP” protection disabled

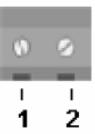
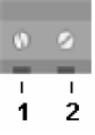
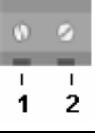
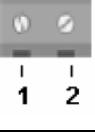
**Table 7. Connector pinout description**

Name	Reference	Description\pinout
J1		Hall sensor/encoder input connector 1 - Hall sensor input 1/encoder A+ 2 - Hall sensor input 2/encoder B+ 3 - Hall sensor input 3/encoder Z+ 4 - 5 VDC 5 - GND
J2		Motor connector A - phase A B - phase B C - phase C

**Table 7. Connector pinout description (continued)**

Name	Reference	Description\pinout
J3		Motor control connector 1 - emergency stop 2 - GND 3 - PWM - 1H 4 - GND 5 - PWM-1L 6 - GND 7 - PWM-2H 8 - GND 9 - PWM-2L 10 - GND 11 - PWM-3H 12 - GND 13 - PWM-3L 14 - HV bus voltage 15 - current phase A 16 - GND 17 - current phase B 18 - GND 19 - current phase C 20 - GND 21 - NTC bypass relay 22 - GND 23 - dissipative brake PWM 24 - GND 25 - +V power 26 - heatsink temperature 27 - PFC sync. 28 - VDD_m 29 - PWM VREF 30 - GND 31 - measure phase A 32 - GND 33 - measure phase B 34 - measure phase C
J4		Dissipative brake 1 – open collector 2 – bus voltage

**Table 7. Connector pinout description (continued)**

Name	Reference	Description\pinout
J19		BEMF daughter board connector 1 - phase A 2 - phase B 3 - phase C 4 - bus voltage 5 - 3.3 VDC 6 - VDD_micro 7 - GND 8 - PWM VREF
J20		+15 V auxiliary supply 1 - +15 VDC 2 - GND
J21		DC input 1 - GND 2 - +VDC
J22		AC input 1 - AC input 2 - AC input
J24		Tachometer input connector for AC motor speed loop control 1 - tachometer bias 2 - tachometer input

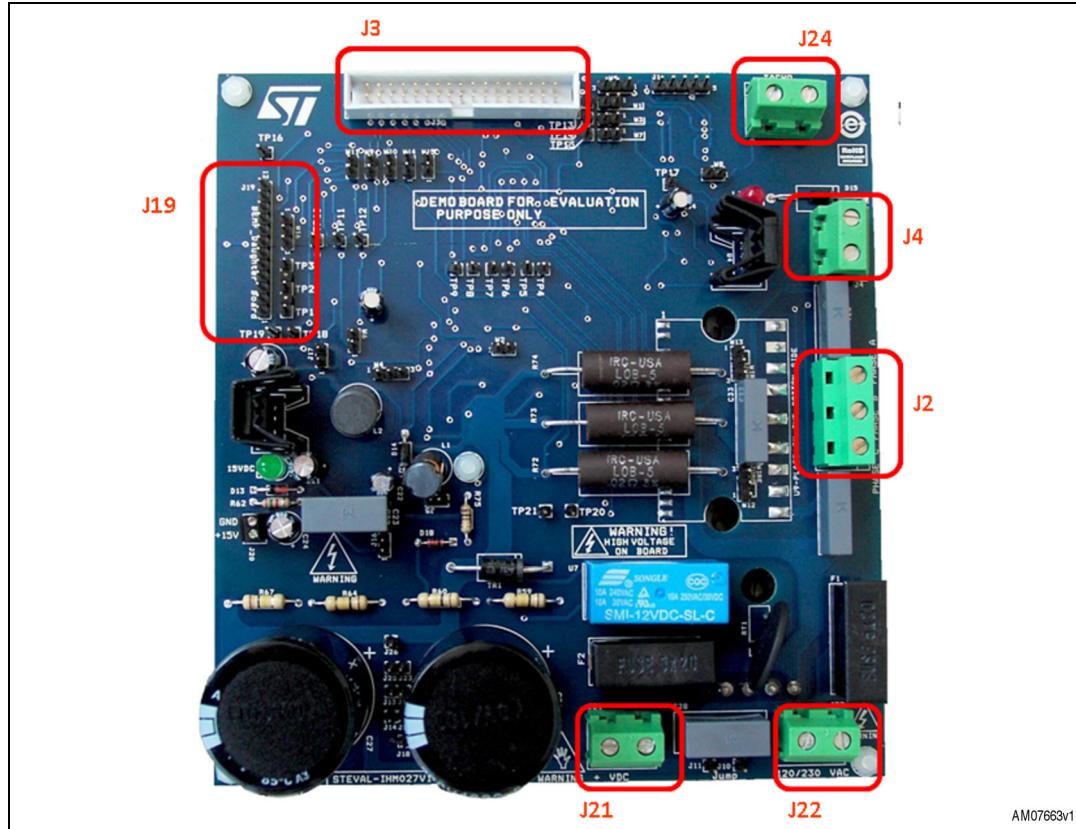
**Table 8. Testing points description**

Test point	Description
TP1	Phase A
TP2	Phase B
TP3	Phase C
TP4	PWM – phase A – low side
TP5	PWM – phase A – high side
TP6	PWM – phase B – low side
TP7	PWM – phase B – high side
TP8	PWM – phase C – low side
TP9	PWM – phase C – high side
TP10	Current phase A
TP11	Current phase B
TP12	Current phase C
TP13	Encoder phase A
TP14	Encoder phase B
TP15	Encoder phase C
TP16	HV bus
TP17	Brake control
TP18	+3.3 V
TP19	+5 V
TP20	+15 V
TP21	GND

## 5 Connector placement

A basic description of the placement of all connectors on the board is visible in [Figure 10](#).

**Figure 10. Connector placement**



## 6 BOM list

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A list of components used to build the demonstration board is shown in [Table 9](#). The majority of the active components used are available from STMicroelectronics.

**Table 9. BOM list**

Reference	Value/part number	Package	Manufacturer
C1, C54	4.7 $\mu$ F/10 V	Elyt. RM05mm	KEMET
C2,C5,C7,C14,C15,C16,C18,C37, C47,C55	100 nF/50 V	SMD 1206	KEMET
C3,C6,C12	33 pF/10 V	SMD 1206	KEMET
C4,C8,C9,C10,C11,C13	10 pF/10 V	SMD 1206	KEMET
C17	2.2 nF/10 V	SMD 1206	KEMET
C19	470 pF/10 V	SMD 1206	KEMET
C20,C27	1000 $\mu$ /200 V	Elyt. RM30mm	KEMET
C21, C24,C29	100 $\mu$ F-25 V	Elyt. RM 150mils	KEMET
C22	2.2 $\mu$ F/25 V	Elyt. RM05mm	KEMET
C23, C28	220 nF/275 VAC X2	Polyester CK18	KEMET
C25,C30	1 $\mu$ F/16 V	SMD 1206	KEMET
C26	47 nF/16 V	SMD 1206	KEMET
C31,C32,C33	10 nF/400 V	Polyester CK18	KEMET
C34,C35,C38,C39,C43,C44	2.2 $\mu$ F/50 V	SMD 1206	KEMET
C36	470 nF/25 V	SMD 1206	KEMET
C41,C42,C45	10 nF/10 V	SMD 1206	KEMET
C46	4.7 nF/10 V	SMD 1206	KEMET
C48	220 nF/50 V	SMD 1206	KEMET
C49	100 pF/10 V	SMD 1206	KEMET

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Table 9. BOM list (continued)

Reference	Value/part number	Package	Manufacturer
D1,D2,D3,D4,D5,D6,D7,D8,D16,D19	BAR43	SOT23	STMicroelectronics
D10	STTH1L06A	SMD 1206	STMicroelectronics
D18,D21	1N4148	DO35	Any
D11	KBU6M	Diode Bridge,250 VAC, 6 A	Any
D12	BZX84C18	MiniMelf	Any
D13	BZX85C16	MiniMelf	Any
D14	STTH1L06	DO-41	STMicroelectronics
D15	STTH108	DO-41	STMicroelectronics
D17,D20	BZX84C13V	MiniMelf	Any
F1,F2	Fuse holder	5x20 mm	Any
Fuse	6 A	20x5 mm	Any
IC2	L7805CP	TO220FP	STMicroelectronics
LD1	Green LED	Universal LED 3 mm, 2 mA	Any
LD2	Red LED	Universal LED 3 mm, 2 mA	Any
L1	47 $\mu$ H	SMD CHOKE 0.5 A	MAGNETICA
L2	2.2 mH	SMD CHOKE 0.25 A	MAGNETICA
T1,Q1,Q2,Q5,Q7,Q8,Q9,Q10,Q11	2STR1230	SOT-23	STMicroelectronics
Q3,Q6	2STR2230	SOT-23	STMicroelectronics
Q4	STGF7NC60HD	TO220FP	STMicroelectronics
RT1	NTC 10 $\Omega$	EPCOS B57364S100M	EPCOS
R1,R2,R3,R5,R8,R9,R10,R16,R26	4.7 k $\Omega$	SMD 1206	Any
R4,R7,R15,R18,R27,R28	560 $\Omega$	SMD 1206	Any
R6,R11,R19,R20,R25,R29,R30,R87	1 k $\Omega$	SMD 1206	Any
R12,R13,R21,R22,R31,R32	2.7 k $\Omega$	SMD 1206	Any
R14	470 $\Omega$	SMD 1206	Any

Table 9. BOM list (continued)

Reference	Value/part number	Package	Manufacturer
R17,R83	2.2 kΩ	SMD 1206	Any
R23,R99	5.6 kΩ	SMD 1206	Any
R24	22 Ω	SMD 1206	Any
R33,R35,R36,R44,R49,R76,R79R84	10 kΩ	SMD 1206	Any
R37,R54,R56,R69,R70,R71,R75R78	100 Ω	SMD 1206	Any
R38,R39,R40,R41,R42,R43,R92	47 kΩ	SMD 1206	Any
R45,R95	68 kΩ	SMD 1206	Any
R46,R88	100 kΩ	SMD 1206	Any
R48,R85	6.8 kΩ	SMD 1206	Any
R52	22 kΩ	SMD 1206	Any
R53,R57,R94	220 Ω	SMD 1206	Any
R55	680 Ω	SMD 1206	Any
R58,R77	1.8 kΩ	SMD 1206	Any
R59,R60,R64,R67	100 k-1/2 W	RC06	Any
R61,R63,R80,R81	470 kΩ	SMD 1206	Any
R62	1.5 kΩ	SMD 1206	Any
R65	8.2 kΩ	SMD 1206	Any
R72,R73,R74	0.1/5 W	Low inductance sense resistor	Any
R82	27 kΩ	SMD 1206	Any
R86,R91	12 kΩ	SMD 1206	Any
R89	5.6 kΩ	SMD 1206	Any
R90	120 Ω	SMD 1206	Any
R96	220 kΩ	SMD 1206	Any
R98	15 kΩ	SMD 1206	Any
TR1	1.5KE400A	DO-201	STMicroelectronics

**Table 9. BOM list (continued)**

Reference	Value/part number	Package	Manufacturer
U1	TSV944	SO-14	STMicroelectronics
U2	M74HC08	SO-14	STMicroelectronics
U3	M74HC367M1R	SO-16	STMicroelectronics
U5	LD1117D33	SO-8	STMicroelectronics
U6,U8	TS391ILT	SOT23-5	STMicroelectronics
U7	RELAY10A	RELAY	Finder
U9	STGIPS10K60A	SSDIP-25L	STMicroelectronics
U10	VIPER16LN	SO-16	STMicroelectronics

## 7 PCB layout

For this application a standard, double-layer, coppered PCB with a ~45  $\mu\text{m}$  copper thickness was selected. The PCB material is FR-4. The dimensions of the board are:

- Length: 147 mm
- Width: 157 mm
- PCB thickness: 1.55 mm

Figure 11. Copper tracks - top side

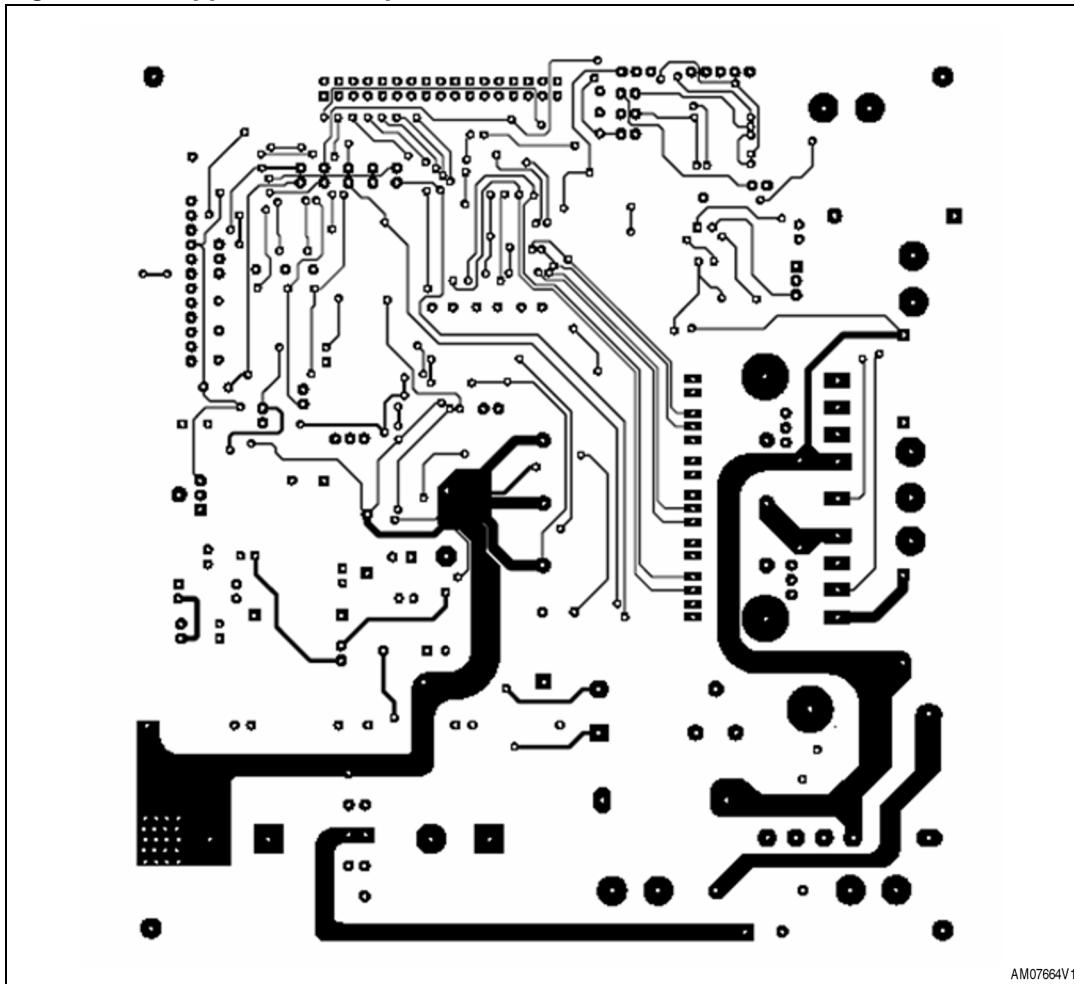


Figure 12. Copper tracks - bottom side

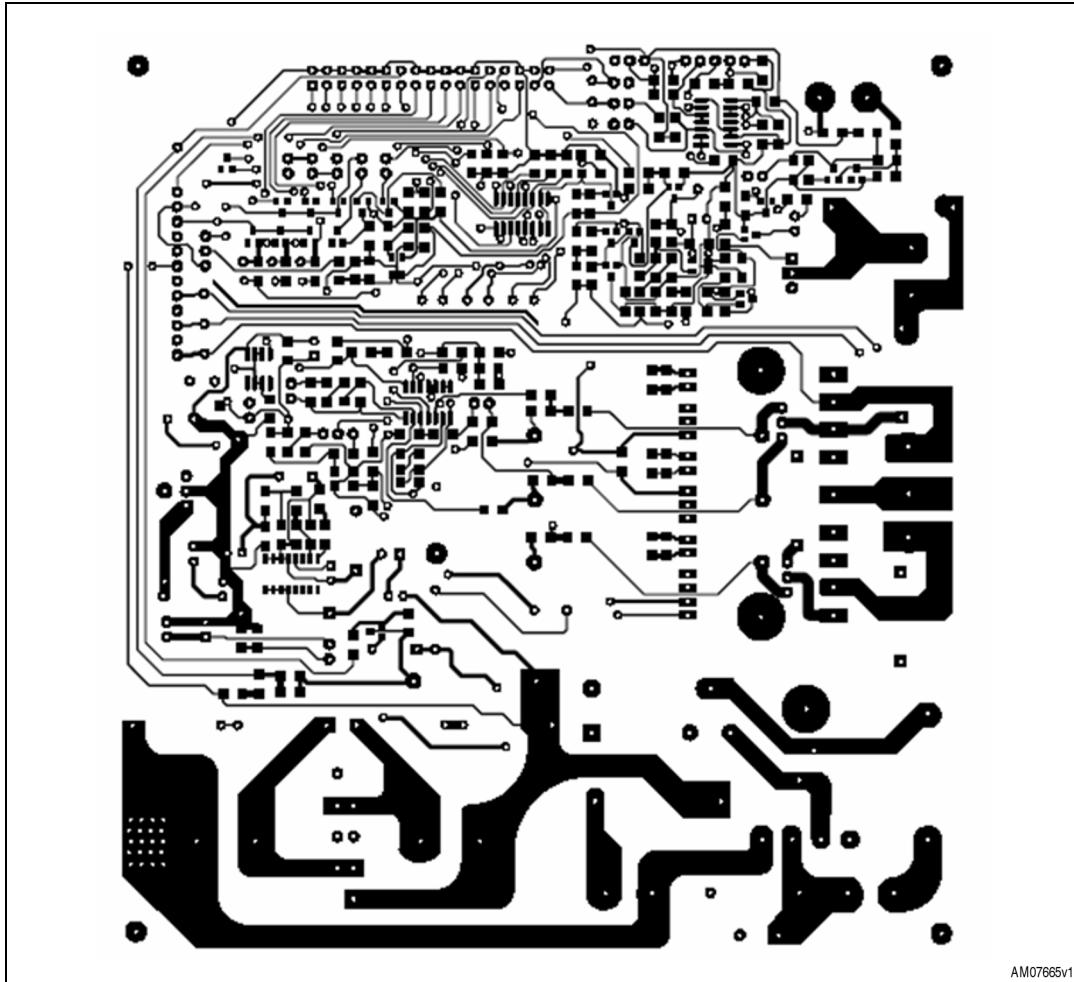


Figure 13. Silk screen - top side

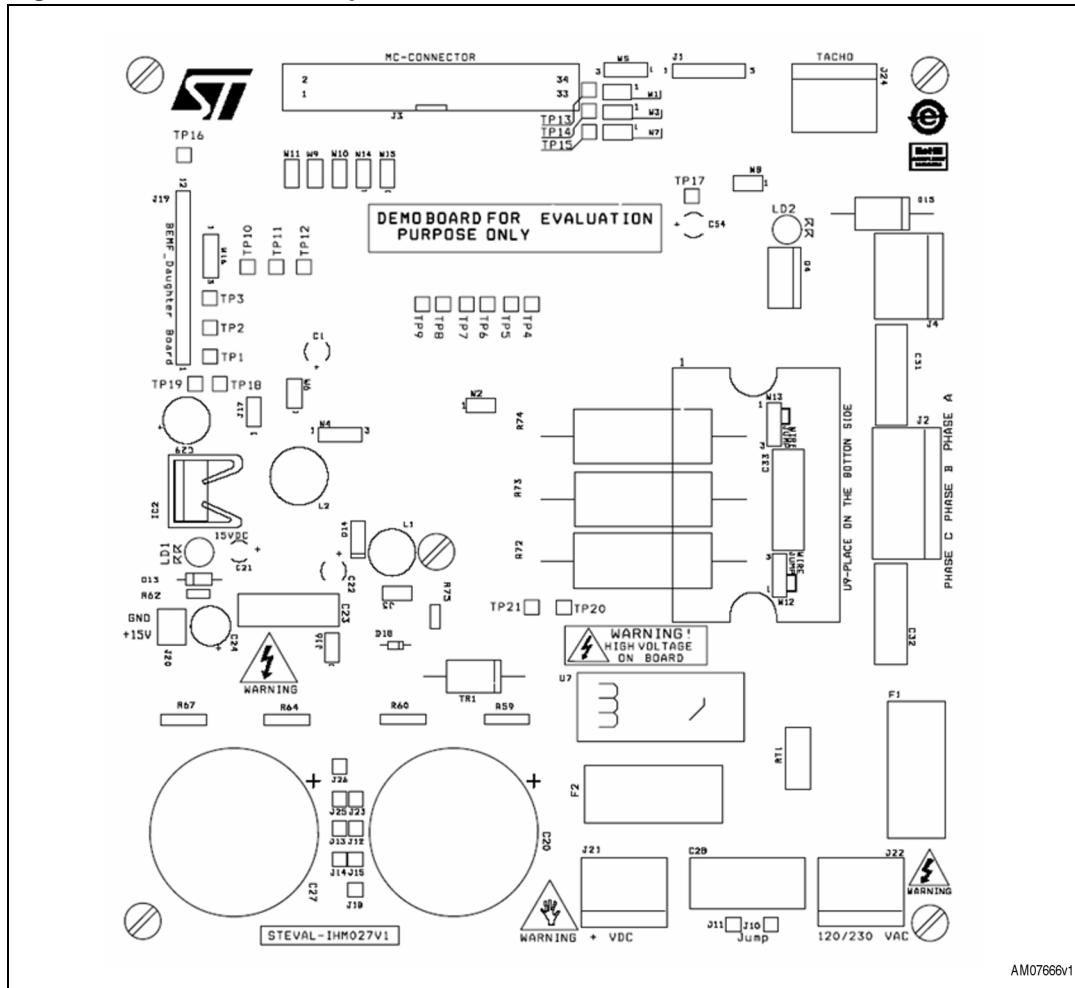
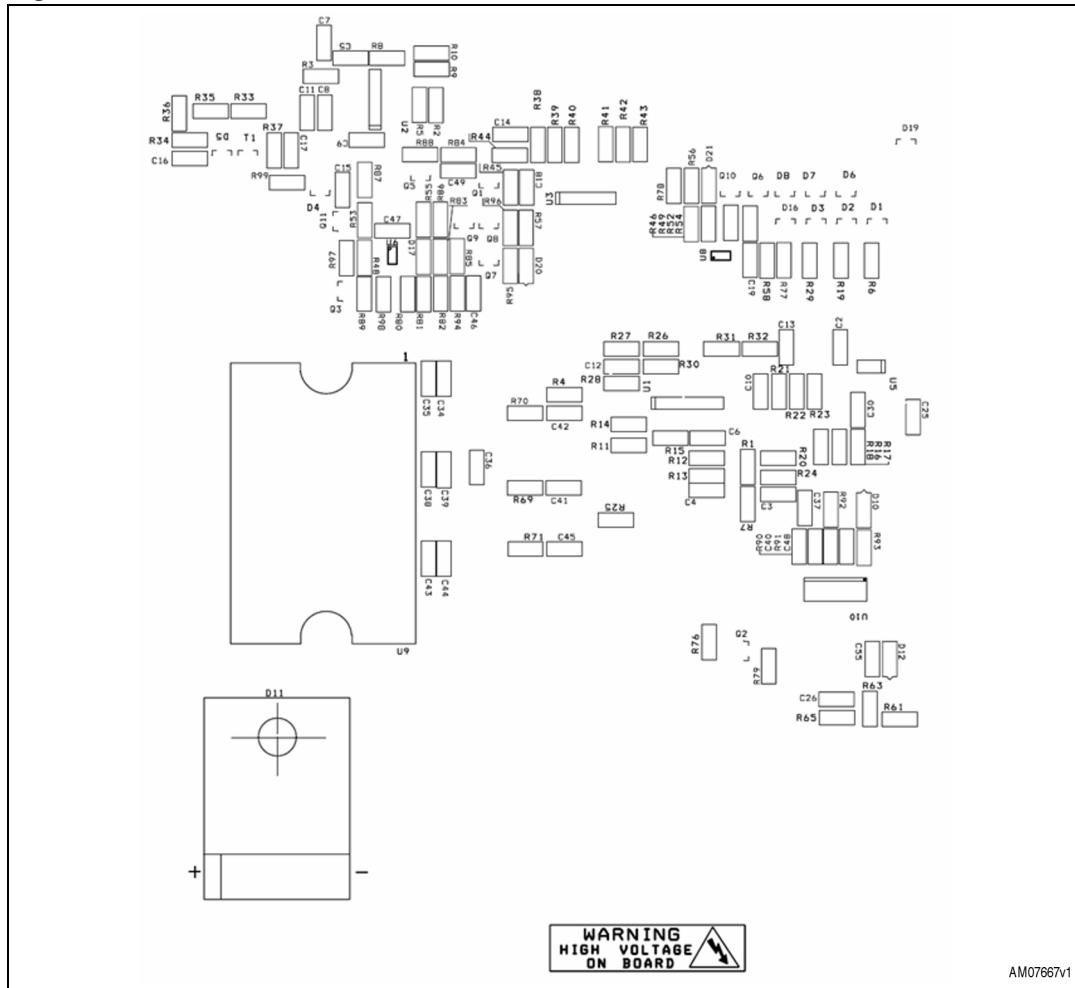


Figure 14. Silk screen - bottom side



## 8 Power losses and dissipation

The power dissipation of the IPM, during normal working, is due to the conduction and switching losses of IGBTs and diodes. The losses during the turn-off steady-state can be ignored, because of their very small amount, and because of the minor effect of increasing the temperature in the device.

The conduction losses depend on the static electrical characteristics of the device (i.e. saturation voltage), therefore, they are a function of the conduction current and the device's junction temperature.

On the other hand, the switching loss is determined by the dynamic characteristics, like turn-on/off time and overvoltage/current. Therefore, in order to obtain an accurate estimation of the switching losses, it is necessary to consider the DC-link voltage of the system, the applied switching frequency, the sinusoidal carrier frequency, and the power circuit layout in addition to the load current and junction temperature.

In this chapter, simple equations for calculating the average power dissipation of the STGIPS10K60A are shown. The power loss calculation intends to provide users with a way of selecting a matched power device, however, it is not expected to be used for thermal dissipation design.

### 8.1 Assumptions

- PWM controlled inverter with sinusoidal output
- PWM signals are generated by the comparison between a sinusoidal waveform (at a  $f_{\text{sine}}$  frequency) and a triangular waveform (at a  $f_{\text{sw}}$  frequency)
- Duty amplitude of PWM signals varies between  $(1-m_a)/2$  and  $(1+m_a)/2$  where  $m_a$  is the PWM modulation index
- Output current is sinusoidal ( $i=I_{\text{peak}}\cos(\theta - \phi)$ ) and it does not include ripple
- Power factor of load output current is  $\cos(\phi)$ ; ideal inductive load is used for switching

### 8.2 Conduction loss

The typical characteristics of forward drop voltage (at  $T_{j\max}$ ) are approximated by the following linear equation for the IGBT and the diode, respectively.

#### Equation 10

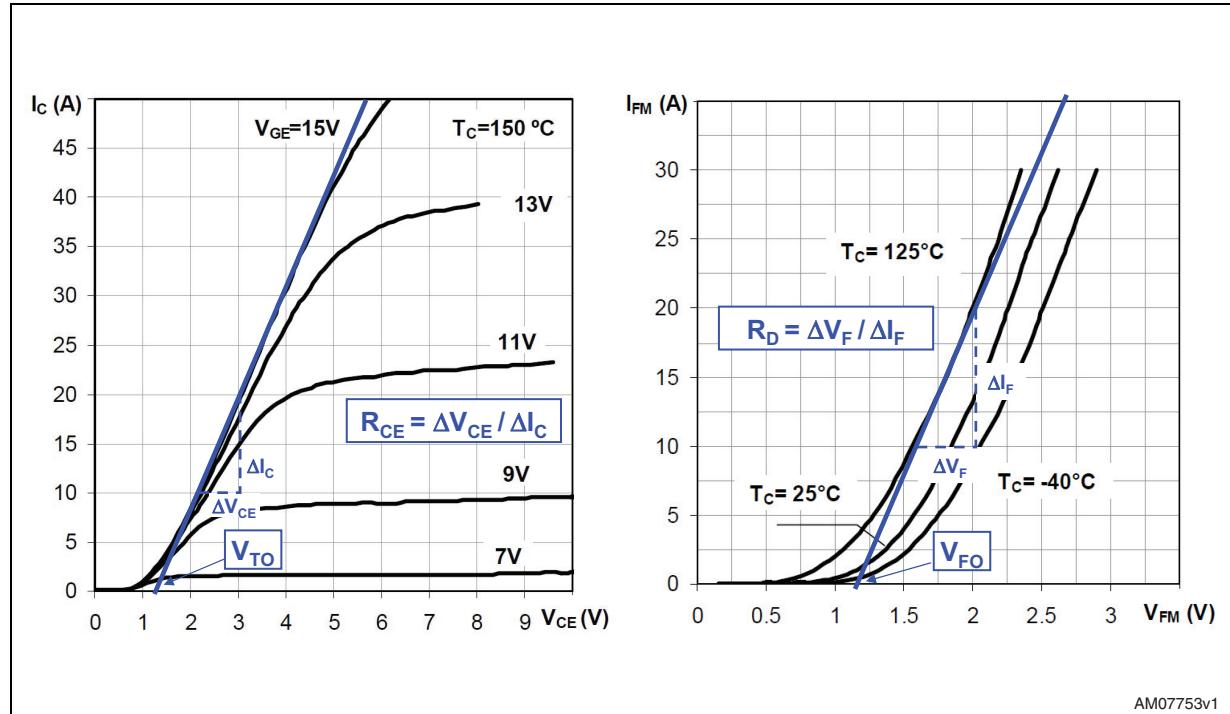
$$V_{\text{cesat}} = V_{\text{to\_I}} + R_{\text{ce\_I}} \cdot i$$

$$V_f = V_{\text{to\_D}} + R_{\text{d\_D}} \cdot i$$

- $V_{\text{to\_I}}$  = threshold voltage of IGBT
- $V_{\text{to\_D}}$  = threshold voltage of diode
- $R_{\text{ce\_I}}$  = on-state slope resistance of IGBT
- $R_{\text{d\_D}}$  = on-state slope resistance of diode

Figure 15 shows how to calculate the relevant parameters (values reported are not referred to the STGIPS10K60A).

Figure 15. Static parameter calculations



Assuming that the switching frequency is high, the output current of the PWM-inverter can be assumed to be sinusoidal.

Equation 11

$$i = I_{peak} \cos(\theta - \phi)$$

where  $\phi$  is the phase-angle difference between output voltage and current.

Using Equation 10, the conduction loss of one IGBT and diode can be obtained as follows:

Equation 12

$$P_{con,I} = \frac{V_I I_{peak}}{2\pi} \int_{-\frac{\pi}{2}+\phi}^{\frac{\pi}{2}+\phi} \xi \cos(\theta - \phi) d\theta + \frac{R_I I_{peak}^2}{2\pi} \int_{-\frac{\pi}{2}+\phi}^{\frac{\pi}{2}+\phi} \xi \cos^2(\theta - \phi) d\theta$$

Equation 13

$$P_{con,D} = \frac{V_D I_{peak}}{2\pi} \int_{-\frac{\pi}{2}+\phi}^{\frac{\pi}{2}+\phi} (1 - \xi) \cos(\theta - \phi) d\theta + \frac{R_D I_{peak}^2}{2\pi} \int_{-\frac{\pi}{2}+\phi}^{\frac{\pi}{2}+\phi} (1 - \xi) \cos^2(\theta - \phi) d\theta$$

where  $\xi$  is the duty cycle in the given PWM control method:

**Equation 14**

$$\varepsilon = [ 1 + m_a \cos(\theta) ]/2$$

and  $m_a$  is the PWM modulation index (defined as the peak phase voltage divided by the half of dc link voltage). Finally, the integration of [Equation 12](#) and [Equation 13](#) gives:

**Equation 15**

$$\begin{aligned} P_{con} &= P_{con,I} + P_{con,D} \\ &= \frac{I_{peak}}{2\pi} (V_I + V_D) + \frac{I_{peak}}{8} (V_I - V_D) MI \cos \phi + \frac{I_{peak}^2}{8} (R_I + R_D) + \frac{I_{peak}^2}{3\pi} (R_I - R_D) MI \cos \phi \end{aligned}$$

It should be noted that the total IPM conduction losses are six times the calculated  $P_{con}$ .

## 8.3 Switching loss

Switching losses can be divided into: turn-on power dissipation and turn-off power dissipation. The dynamic performances of the IGBT are strictly related to many parameters (voltage, current, temperature, etc.) so it is possible to make some assumptions to simplify the calculations. If the output current is sinusoidal, it is true if the switching frequency is high enough, also the switching power losses are sinusoidal:

**Equation 16**

$$E_{on}(\theta) = E_{on\_peak} \cos(\theta - \phi)$$

$$E_{off}(\theta) = E_{off\_peak} \cos(\theta - \phi)$$

where  $E_{on\_peak}$  and  $E_{off\_peak}$  are the maximum value @  $T_{jmax}$  and  $I_{cpeak}$ .

Using [Equation 16](#), the switching losses can be obtained as follows:

**Equation 17**

$$\begin{aligned} P_{sw} &= \frac{1}{2\pi} \int_{\frac{\pi}{2}+\phi}^{\frac{\pi}{2}+\phi} (E_{on} + E_{off}) f_{sw} d\theta \\ &= \frac{(E_{on\_peak} + E_{off\_peak}) f_{sw}}{2\pi} \int_{\frac{\pi}{2}+\phi}^{\frac{\pi}{2}+\phi} \cos(\theta - \phi) d\theta = \frac{(E_{on\_peak} + E_{off\_peak}) f_{sw}}{\pi} \end{aligned}$$

## 8.4 Thermal impedance overview

Semiconductor devices are very sensitive to junction temperature. This makes the thermal performances analysis of the IPM a very important factor during the application development stage. To start the analysis of the device's thermal behavior, the basic (and

fundamental) concept of thermal resistance must be considered, which is defined as the difference in temperature between two closed isothermal surfaces divided by the total power flow between them, [Equation 18](#).

### Equation 18

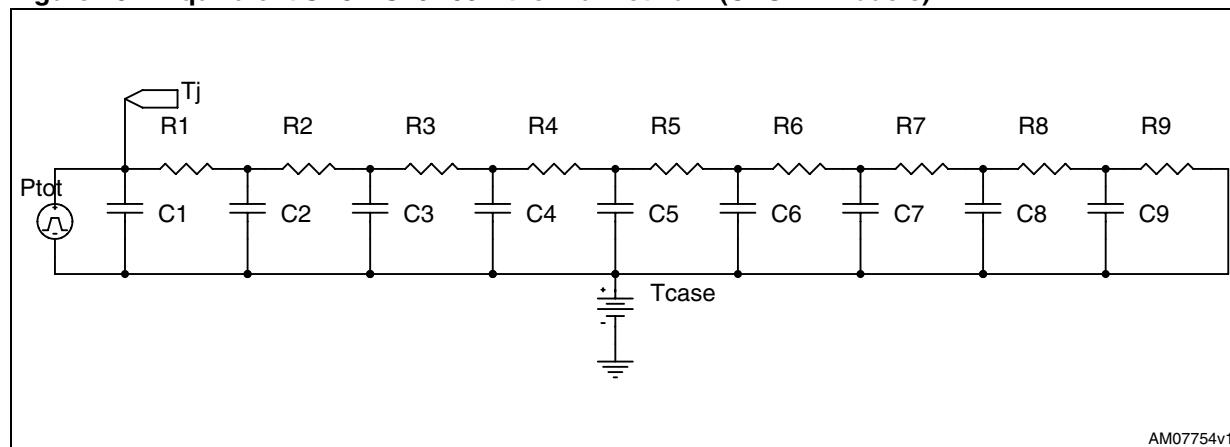
$$R_{\phi c} = \frac{T_j - T_c}{P_D}$$

For semiconductor devices, typically, the important factors are the relation between  $T_j$ , IGBT junction temperature, and a reference temperature,  $T_x$ . The selection of a reference point is arbitrary, but usually the hottest spot on the back of a device, on which a heatsink is attached, is chosen. This is called junction-to-case thermal resistance,  $R_{\phi jc}$ . When the reference point is an ambient temperature, it is called junction-to-ambient thermal resistance,  $R_{\phi ja}$ . Both thermal resistances are used for the characterization of a device's thermal performance.

The thermal resistance of the IPM is strictly related to the assembly process/material: STGIPS10K60A is based on a DBC substrate that guarantees a higher isolation voltage and an excellent thermal resistance value.

In practical operations, the power loss  $P_D$  is cyclic and therefore the transient RC equivalent thermal circuit, see [Figure 16](#) and [Table 10](#) for more details, should be considered. For pulsed power loss, the thermal capacitance effect delays the rise in junction temperature, and therefore permits a heavier loading of the IPM.

**Figure 16. Equivalent STGIPS10K60A thermal network (CAUER models)**



**Table 10. RC - Cauer STGIPS10K60A thermal network**

RC - Cauer STGIPS10K60A thermal network			
R	Value [°C/W]	C	Value [W*s/°C]
R1	0.088	C1	0.32E-3
R2	0.0154	C2	0.63E-3
R3	0.316	C3	0.90E-4
R4	0.395E-2	C4	0.50E-3
R5	0.816	C5	0.50E-2

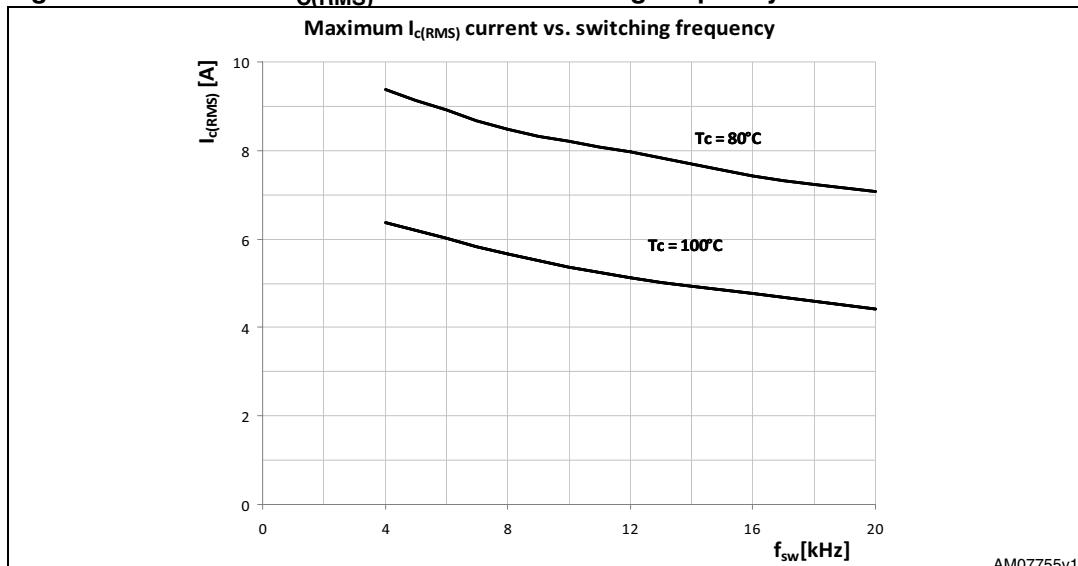
**Table 10. RC - Cauer STGIPS10K60A thermal network (continued)**

RC - Cauer STGIPS10K60A thermal network			
R	Value [°C/W]	C	Value [W*s/°C]
R6	0.432	C6	1.20E-2
R7	0.0123	C7	0.149E-2
R8	0.448	C8	0.809E-3
R9	1.66	C9	0.120

## 8.5 Temperature rise considerations and calculation example

According to the previous mathematical formula, it is possible to simulate (with an accurate software tool) the STGIPS10K60A performances, under certain application conditions.

*Figure 17* shows the results ( $I_{C(RMS)}$  current - which is related to the output motor power vs. fsw) of the power loss simulations.

**Figure 17. Maximum  $I_{C(RMS)}$  current vs. switching frequency**

- Condition:  $V_{PN}=300$  V,  $V_{CC}=V_{BS}=15$  V,  $V_{CE(\text{sat})}$ =typical, switching loss=typical,  $T_j=125$  °C,  $T_c$ =see graph,  $R_{th(j-c)}$  = max.,  $m_a=0.8$ ,  $PF=0.6$ , 3-phase continuous PWM modulation, 60 Hz sine waveform output.

*Note:* The above characteristics may vary in the different control schemes and motor drive types.

## 9 Ordering information

The demonstration board is available through the standard ordering system, the order code is: STEVAL-IHM027V1. The items delivered include the assembled board, board documentation, PCB fabrication data such as gerber files, assembly files (pick and place), and component documentation.

## 10 **Using the STEVAL-IHM027V1 with STM32 FOC firmware library**

The STM32 FOC firmware library v2.0 is a firmware library running on the STM3210B-MCKIT which allows the performing of the FOC of a PMSM (or ACIM) in a configuration with and without sensors.

## 11 Environmental considerations

---

**Warning:** The STEVAL-IHM027V1 demonstration board must only be used in a power laboratory. The voltage used in the drive system presents a shock hazard.

---

The kit is not electrically isolated from the DC input. This topology is very common in motor drives. The microprocessor is grounded by the integrated ground of the DC bus. The microprocessor and associated circuitry are hot and MUST be isolated from user controls and communication interfaces.

---

**Warning:** All measuring equipment must be isolated from the main power supply before powering up the motor drive. To use an oscilloscope with the kit, it is safer to isolate the DC supply AND the oscilloscope. This prevents shock occurring as a result of touching any SINGLE point in the circuit, but does NOT prevent shock when touching two or more points in the circuit.

---

## 12 Hardware requirements

To run the STEVAL-IHM027V1 together with the STM32 FOC firmware library, the following items are required:

- The board: STEVAL-IHM027V1
- High voltage insulated AC power supply up to 230 VAC
- J-link programmer (not included in the package)
- J-link insulating board (not included in the package)
- 3-phase brushless motor with permanent magnet rotor or a generic 3-phase induction motor (not included in the package)
- Insulated oscilloscope (as needed)
- Insulated multimeter (as needed).

## 13 Software requirements

To customize, compile, and download the STM32 FOC firmware library v2.0 motor control firmware, the IAR tool “EWARM v5.30” must be installed. The free 32 kB limited version (referenced as “IAR Kickstand Kit™” version) is available for download at <http://supp.iar.com/Download>.

## 14 Conclusion

This document describes the 1 kW 3-phase motor control STEVAL-IHM027V1 demonstration board based on IPM as a universal fully-evaluated platform.

## 15 References

1. STGIPS10K60A datasheet
2. Viper16 datasheet
3. STGF10NC60KD datasheet
4. UM0379
5. UM0723

## 16 Revision history

**Table 11. Document revision history**

Date	Revision	Changes
08-Nov-2010	1	Initial release.
21-Feb-2012	2	Modified: schematics

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